Fermi National Accelerator Laboratory

FERMILAB-Pub-77/34-EXP
7200.311
(Submitted to Phys. Rev. Lett.)

INCLUSIVE ρ^0 AND f^0 PRODUCTION IN 100 GeV/c $\bar{p}p$ INTERACTIONS

R. Raja, C. T. Murphy, and L. Voyvodic
Fermi National Accelerator Laboratory
Batavia, Illinois 60510 USA

and

R. E. Ansorge, C. P. Bust, J. R. Carter, W. W. Neale,
J. G. Rushbrooke, and D. R. Ward
Cavendish Laboratory, Cambridge, England

and

B. Y. Oh, M. Pratap, G. Sionakides, G. A. Smith, and J. Whitmore
Michigan State University
East Lansing, Michigan 48824 USA

April 1977

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

Inclusive ρ° and f° Production in 100 GeV/c $\bar{p}p$ Interactions

R. Raja, C. T. Murphy, L. Voyvodic
Fermi National Accelerator Laboratory
Batavia, Illinois 60510 U.S.A.

R. E. Ansorge, C. P. Bust, J.R. Carter, W. W. Neale,
J. G. Rushbrooke and D. R. Ward*
Cavendish Laboratory, Cambridge, England

B. Y. Oh, M. Pratap, G. Sionakides, G. A. Smith and J. Whitmore†
Michigan State University
East Lansing, Michigan 48824, U.S.A.

ABSTRACT

Inclusive and semi-inclusive ρ° production in 100 GeV/c $\bar{p}p$ interactions has been studied as a function of C.M. rapidity and transverse momentum. Cross sections are compared with those for $\bar{p}p$ interactions at other energies, as well as pp and $\pi^{\pm}p$ interactions, over the range $\sim 2 < p_{lab} < 200$ GeV/c. A measurement of the f° production cross section has been made. Calculations of the contribution from ρ° decay to prompt lepton production are presented.

April, 1977

---

* Work supported by the Science Research Council, U.K.

† Work supported in part by the National Science Foundation, U.S.A.

Very little is known about inclusive meson resonance production in high energy antiproton-proton collisions, the highest energy results available being at 12 GeV/c[1]. From correlation studies in high energy collisions, there is mounting evidence that most of the final state particles result from the decay of particle clusters and some[2] have interpreted these clusters as being resonances. An experimental determination of resonance production cross sections is therefore of importance. Also, by a comparison of $\bar{p}p$ data with the results obtained in pp interactions, one may investigate the extent of meson resonance production in annihilation events. In view of the fact that little is known about the properties of $\bar{p}p$ annihilation above 12 GeV/c[1], this is an important first step in understanding this process at high energies. Finally, current studies of direct lepton production in hadronic reactions suggest that meson resonance decay is an obvious source of leptons and, in particular, has not been measured in $\bar{p}p$ interactions above $\sim$20 GeV/c.

The data presented here were obtained from a 98,000 picture exposure of the 30-inch bubble chamber-wide gap spark chamber hybrid system at Fermilab[3]. Data on particle multiplicities, neutral particles and $\pi^{\pm}$ production have been published elsewhere[4]. The results presented here are based on an inclusive sample of 9364 inelastic events. Figure 1(a) shows the $\pi^+\pi^-$ mass distribution for all inelastic events. All tracks which are not identified as a proton by ionization ($p_{lab} > 1.4$ GeV/c) have been included as $\pi^{\pm}$. The $\pi^{\pm}\pi^{\pm}$ mass distribution (not shown) shows no structure and is reasonably well fitted (in the region $0.5 < m_{\pi\pi} < 1.0$ GeV/c) by a smooth exponential function of mass.

The average mass resolution for ρ°'s produced in the central region is estimated to be $\simeq \pm 50$ MeV. A fit to the inclusive $\pi^+\pi^-$ mass spectrum was performed in the mass region 0.5 - 1.0 GeV using an exponential background and a p-wave Breit-Wigner formula[5] with the mass and width of the ρ° allowed to vary. We find (3050 ± 400) ρ°'s above background with $M(\rho^\circ) = (734 \pm 10)$ MeV and $\Gamma(\rho^\circ) = (175 \pm 10)$ MeV. Based on this fit (shown as the solid line in Fig. 1(a)) we determine that there are (0.33 ±0.06) ρ°'s per inelastic event, corresponding to an inclusive cross section of (11.4 ± 2.5)mb. This indicates that ∿12.5% of the $\pi^\pm$'s are the result of ρ° decay. We note that the ρ° mass given by the fit is substantially lower than its commonly quoted value of (773 ± 3) MeV[6]. A similar shift in the ρ° mass has been observed in $\bar{p}p$ reactions previously.[7]

Figure 2 shows the inclusive ρ° cross section plotted as a function of beam momentum for pp[8], $\bar{p}p$ [1,9] and $\pi^\pm p$ [10] interactions. The data are consistent with a logarithmic rise with p_{lab} with the exception of $\bar{p}p$ at low energies. The rapid fall and then slow rise of the inclusive ρ° cross section in $\bar{p}p$ interactions is similar to that observed for inclusive $\pi^\pm$ production[4] and is presumably related to the different energy dependences of the nonannihilation and annihilation contributions. A fit to the formula $\sigma = A \log(p_{lab}) + B$ gives the value (7.3 ± 0.7) mb for the 100 GeV/c pp inclusive ρ° cross section. The difference between ρ° cross sections in $\bar{p}p$ and pp interactions at 100 GeV/c is therefore (4.1 ± 2.2) mb and may be interpreted as the annihilation component of $\bar{p}p \to \rho^\circ X$. We note that at 12 GeV/c, Gall et al.[1] quote a $\bar{p}p \to \rho^\circ$ inclusive cross section of (6.5 ± 0.5) mb, of which (4.4 ± 0.4) mb is

due to annihilations. Subtraction of $\bar{p}p$ and pp ρ° cross sections at 12 GeV/c yields (4.7 ± 0.6) mb; hence identifying $\bar{p}p$ and pp differences as the annihilation contribution appears to be a reasonable first approximation. Since the difference between $\bar{p}p$ and pp inelastic cross sections[4] at 100 GeV/c is (2.7 ± 0.7) mb, the above discussion suggests that there are (1.5 ± 0.8) ρ°'s per annihilation event. We also note that in a sample of $\bar{p}p$ nonannihilation events with a slow proton ($p_{lab} < 1.4$ GeV/c) there is an average of (0.21 ± 0.04) ρ°'s/event, suggesting that annihilation events are substantially richer in ρ°'s than nonannihilation events.

To obtain semi-inclusive ρ° cross sections, the mass and width of the ρ° was fixed at 734 and 174 MeV respectively and fits were carried out on the semi-inclusive $\pi^+\pi^-$ mass spectra (see, for example, Figure 1(b-d)), subject to the condition that the semi-inclusive cross sections add up to the inclusive cross section as determined above. The results obtained are presented in Table 1. The data indicate that ρ°'s are associated, on the average, with higher charged multiplicities, than, for example, neutral pions.[4]

To investigate the production characteristics of ρ°'s, the data were divided into different ranges of the center of mass rapidity of the $\pi^+\pi^-$ combination and fits to the mass distribution were carried out for each rapidity range. It is observed (Fig. 3(a)) that ρ° production is dominantly central, the width of the rapidity distribution at half maximum being approximately one unit, similar to that observed for γ's.[4] By comparison with 12 GeV/c data[1], it is seen that the rise in the ρ° cross section between 12 and 100 GeV/c is mainly due to the increase in the range of available rapidity and not due to an increase in central production.

This is in distinct contrast to the pp case[11]. The different energy dependences of the two components in $\bar{p}p$ interactions may also be responsible for this feature, rather than any intrinsic scaling behavior.

The transverse momentum distribution of ρ°'s is found to be consistent with an exponential in p_T^2, the slope (2.2 ± 0.8 $(GeV/c)^{-2}$) being smaller than that observed at 12 GeV/c (4.1 ± 0.4 $(GeV/c)^{-2}$). The average transverse momentum of ρ°'s is (0.54 ± 0.12) GeV/c, a value substantially larger than that for γ's, K_S°'s and $\pi^\pm$'s (0.345 ± 0.002 GeV/c) in this experiment.[4] In the higher transverse momentum region, there is evidence for f° production, as illustrated in Figure 3(b) where we show the $\pi^+\pi^-$ mass distribution for $p_T(\pi^+\pi^-) > 1$ GeV/c. In the mass range 1.0 to 1.5 GeV/c, a fit including an exponential background and a d-wave Breit-Wigner contribution, allowing for the branching ratio[6] into $\pi^+\pi^-$, yields an f° cross section of (1.2 ± 0.6) mb for $p_T > 1$ GeV/c.

Using the rapidity and transverse momentum distributions of ρ°'s as determined from this experiment, we have calculated the ρ° contribution to prompt lepton production assuming[6] a $\mu^+\mu^-$ branching fraction of 6.7×10^{-5}. The results are presented in Figure 4, which shows the ρ° contribution to the ratio $(\frac{\mu^-}{\pi^-})$ as a function of p_T and center of mass rapidity, y*. The average ratio $(\frac{\mu^-}{\pi^-})$ is found to be $(0.8 \pm 0.2) \times 10^{-5}$. It will be interesting to compare this result with a measurement of the inclusive muon production in $\bar{p}p$ interactions at this energy in the future.

In conclusion, we have observed several interesting features in ρ° production in high energy $\bar{p}p$ interactions. This analysis suggests an enrichment of ρ°'s in annihilation as compared to nonannihilation process. We observe that most ρ°'s are produced centrally in a manner similar to pions; however, the central production cross section does not increase in the energy range 12 to 100 GeV/c, in contrast to pp collisions. For higher transverse momenta (>1.0 GeV/c) we find evidence for substantial f° production, observed at the level of ~30% of $\pi^\pm$ production and ~90% ρ° production. Finally, the contribution of ρ° decay to a measurement of prompt lepton production in 100 GeV/c $\bar{p}p$ interactions (as yet unmeasured) is expected to be 0.8×10^{-5} of charged pion production.

REFERENCES

1. D. Gall et al., Proceedings of the International Symposium on $\bar{p}p$ Interactions, Loma-Koli, Finland, 1975, p. 414 (Ed. J. Tuominiemi).
2. A. W. Chao and C. Quigg, Phys. Rev. D9, 2016 (1974).
3. G. A. Smith, AIP Conference Proceedings No. 14, Particles and Fields - 1973 (APS/DPF Berkeley), p. 500.
4. R. E. Ansorge et al., Phys. Lett. 59B, 299 (1975); J. G. Rushbrooke et al., Phys. Lett. 59B, 303 (1975); D. R. Ward et al., Phys. Lett. 62B, 237 (1975); R. Raja et al., Phys. Rev. D15, 627 (1977); and J. Whitmore et al., "Properties of Inclusive $\pi^{\pm}$ Production in 100 GeV/c Antiproton-Proton Interactions", to be published in Phys. Rev. Lett. (1977).
5. M. Deutschmann et al., Nucl. Phys. B103, 426 (1976). We have used the Breit-Wigner parametrization described here to obtain (a + b· Breit-Wigner)$e^{-\alpha M}$ for the fitted curve.
6. T. G. Trippe et al., Rev. Mod. Phys. 48, 526 (1976).
7. T. Fields and R. Singer, Proceedings of the IV International Symposium Interactions, Syracuse University, 1975, Vol. 2, page V-1 (Ed. T. Kalogeropoulos and K. Wali).
8. pp data are taken from (12 and 24 GeV/c) V. Blobel et al., Phys. Lett. 48B, 73 (1977);(69 GeV/c) V. Ammosov et al., paper submitted to the EPS International Conference, Palermo, Italy, 1975; and (205 GeV/c) R. Singer et al., Phys. Lett. 60B, 385 (1976).
9. C. K. Chen et al., "$\bar{p}p$ Interactions at 2.32 GeV/c", to be submitted to Nuc. Phys. B (1977).

10. π^-p data taken from: (3.99 GeV/c) B. Haber et al., Phys. Rev. D11, 495 (1975); (8 GeV/c) T. Kitagaki et al., paper submitted to the XVI International Conference on High Energy Physics, Batavia (1972); (11.2 GeV/c) P. Borzatta et al., Nuovo Cimento 15A, 45 (1973) and C. Caso et al., Nuovo Cimento 66A, 11 (1970); (15 GeV/c) J. Brau et al., Nucl. Phys. B99, 232 (1975); (16 GeV/c) J. Bartke et al., Nucl. Phys. B107, 93 (1976); (147 GeV/c) D. Fong et al., Phys. Lett. 60B, 124 (1975); and (205 GeV/c) F. C. Winkelman et al., Phys. Lett. 56B, 101 (1975): π^+p data are taken from: (8, 16 and 23 GeV/c) M. Deutschmann et al., Ref. 5; and (6, 22 GeV/c) H. A. Gordon et al., Phys. Rev. Lett. 34, 284 (1975).

11. J. Whitmore, Physics Reports, 27C, 188 (1976).

TABLE I

SEMI-INCLUSIVE CROSS SECTIONS

Charged Multiplicity	ρ° Cross Section (mb)	$\langle\rho^\circ\rangle$
2	-	-
4	0.45 ± 0.31	$.06 \pm .04$
6	1.18 ± 0.56	0.14 ± 0.07
8	3.75 ± 0.91	0.54 ± 0.13
10	2.03 ± 0.90	0.49 ± 0.21
12	2.14 ± 0.92	0.97 ± 0.42
14	$0.66 \begin{smallmatrix} + .87 \\ - .66 \end{smallmatrix}$	$0.73 \begin{smallmatrix} + .97 \\ - .73 \end{smallmatrix}$
$\geqslant 16$	$1.24 \begin{smallmatrix} + 1.63 \\ - 1.24 \end{smallmatrix}$	$2.3 \begin{smallmatrix} + 3.1 \\ - 2.3 \end{smallmatrix}$
TOTAL	11.4 ± 2.5	0.33 ± 0.06

FIGURE CAPTIONS

Figure 1. The $\pi^+\pi^-$ invariant mass ($m_{\pi^+\pi^-}$) distribution resulting from inelastic events for (a) all (b) six-prong (c) eight-prong and (d) ten-prong events. The curves correspond to fits to a Breit-Wigner form (solid) plus background (dashed).

Figure 2. Inclusive ρ° cross sections for $\bar{p}p$, pp, and $\pi^\pm p$ interactions versus beam laboratory momentum. The curves are drawn to guide the eye.

Figure 3. (a) C.M. ρ° rapidity distribution at 12 GeV/c (Ref. 1) and 100 GeV/c and (b) the $\pi^+\pi^-$ invariant mass ($m_{\pi^+\pi^-}$) distribution for $p_T(\pi^+\pi^-) > 1.0$ GeV/c. The curves correspond to a fit to a Breit-Wigner form (solid) plus background (dashed).

Figure 4. The ratio μ^-/π^- determined in this experiment as a function of the ρ° transverse momentum (p_T) and C. M. rapidity (y^*).

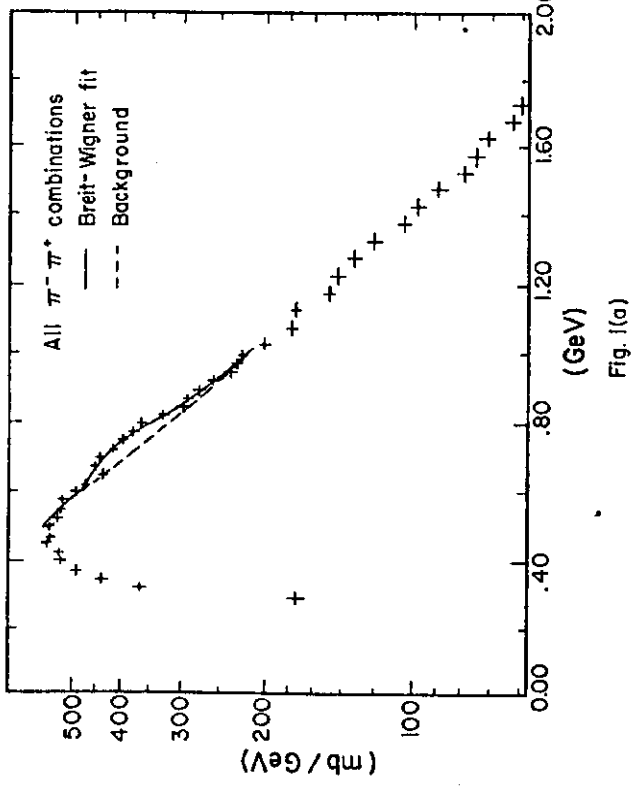

Fig. 1(a)

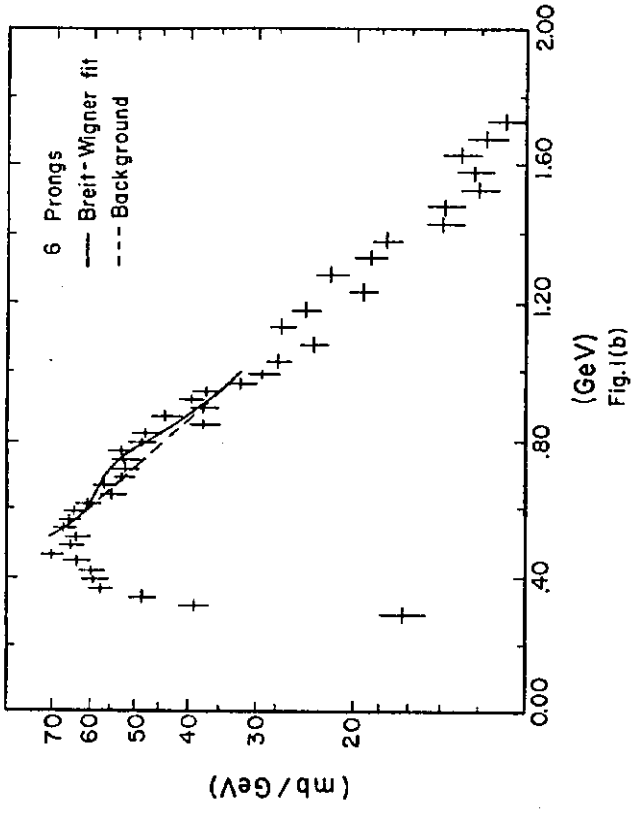

Fig. 1(b)

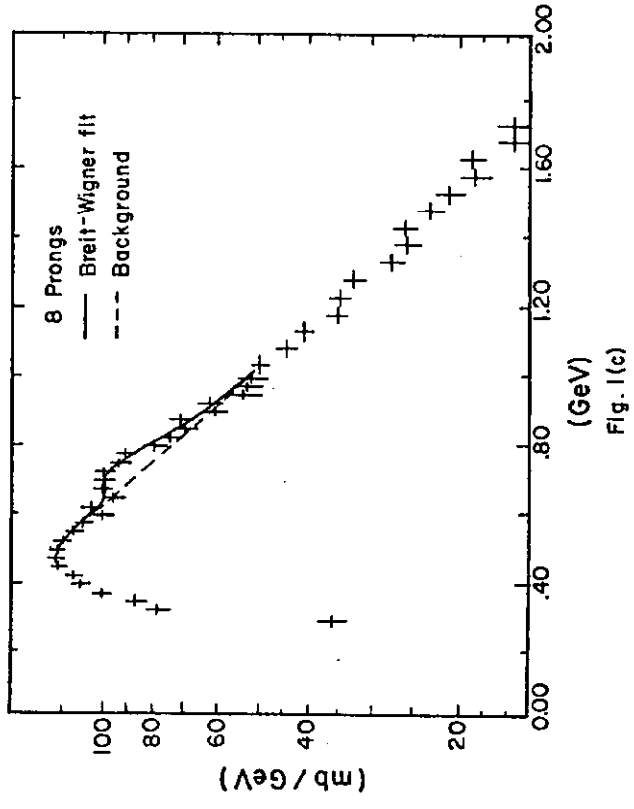

Fig. 1(c)

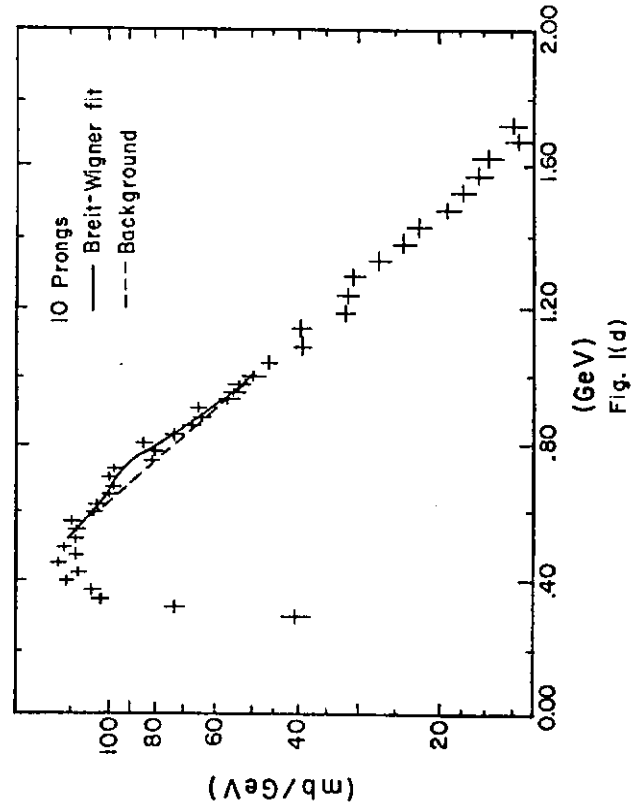

Fig. 1(d)

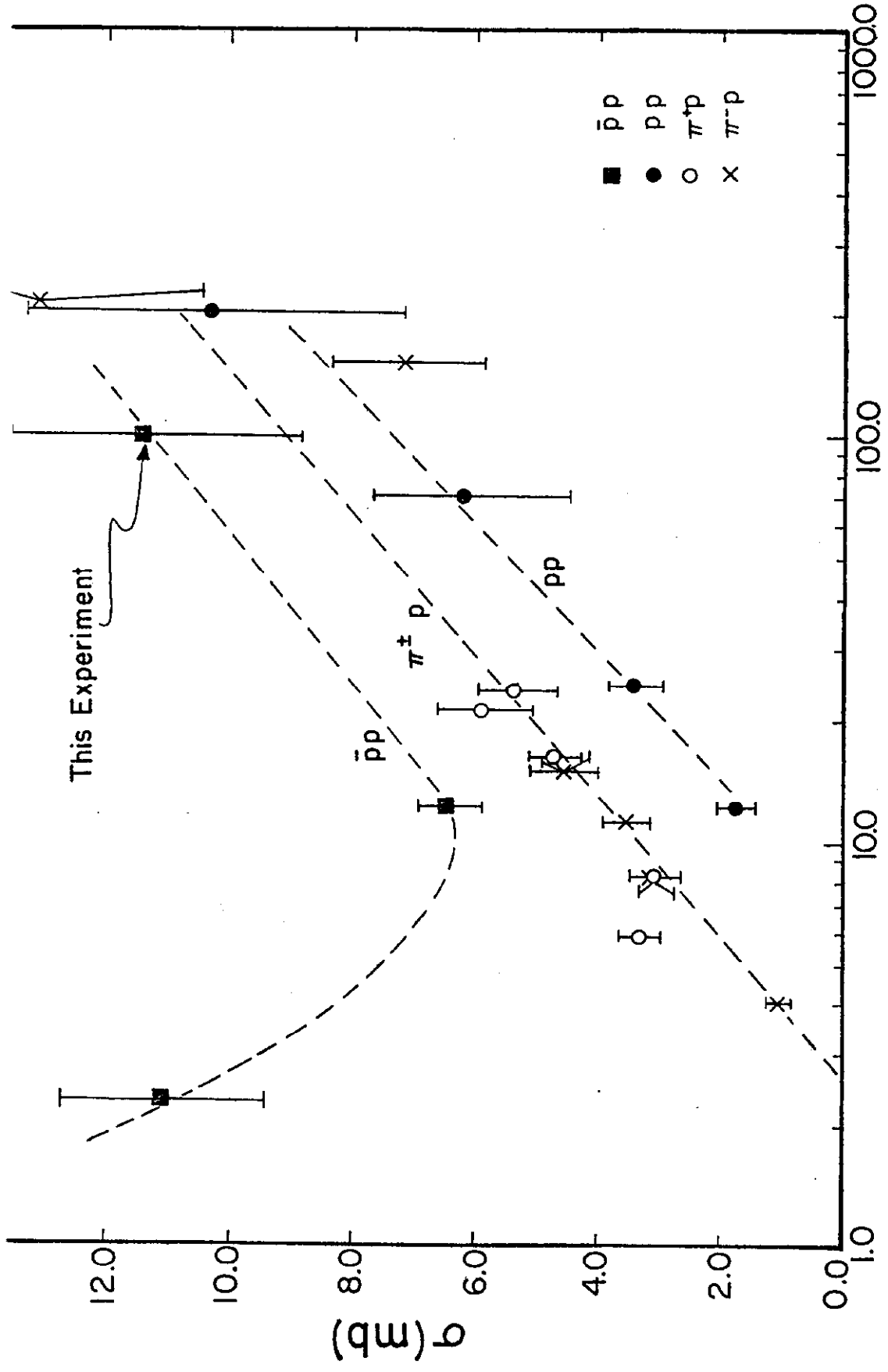
σ (mb)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1.0
10.0
100.0
1000.0
p_{lab} (GeV/c)
This Experiment
$\bar{p}p$
$\pi^{\pm}p$
pp
$\bar{p}p$
pp
π^+p
π^-p

Fig. 2

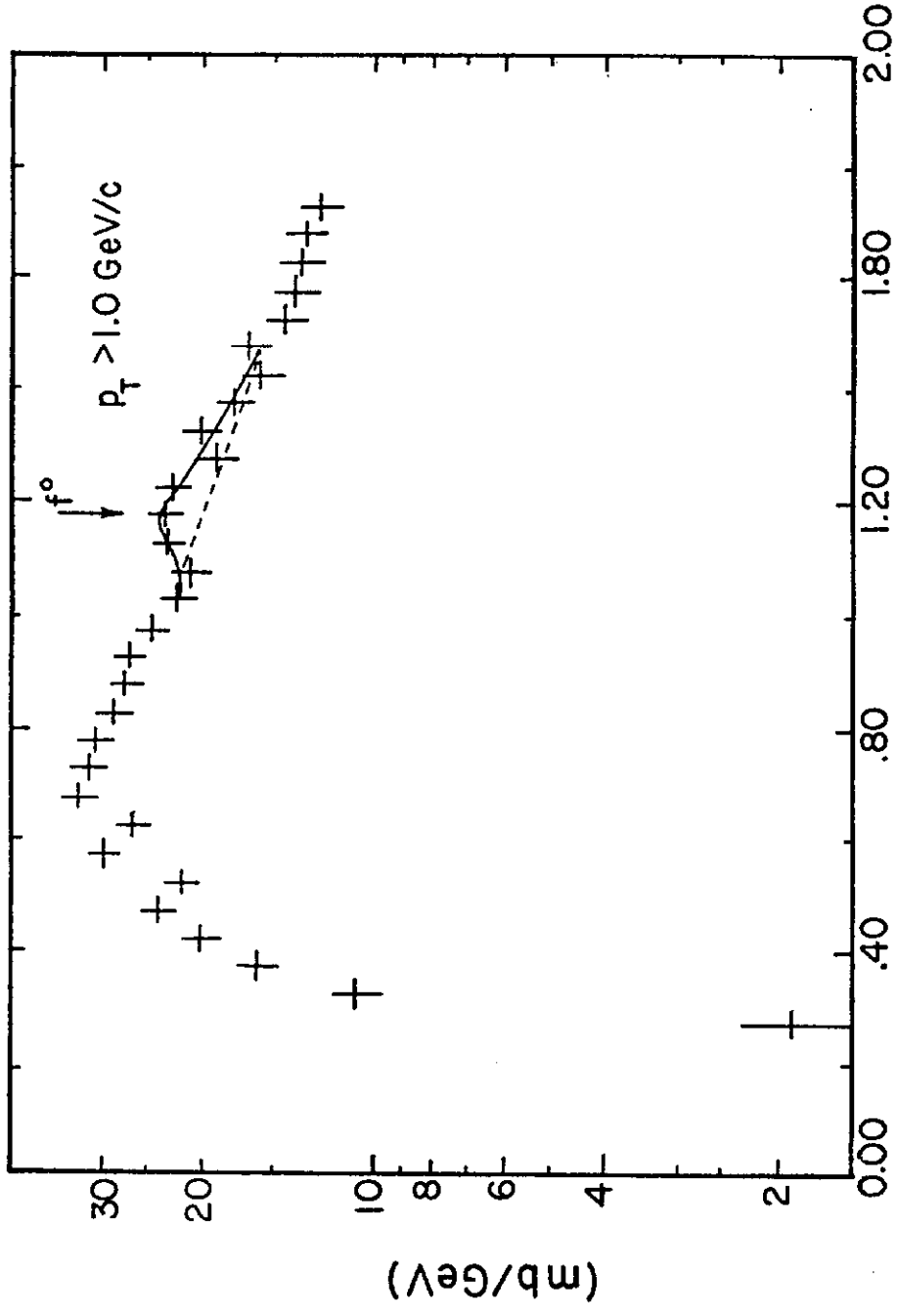

Fig. 3(b)

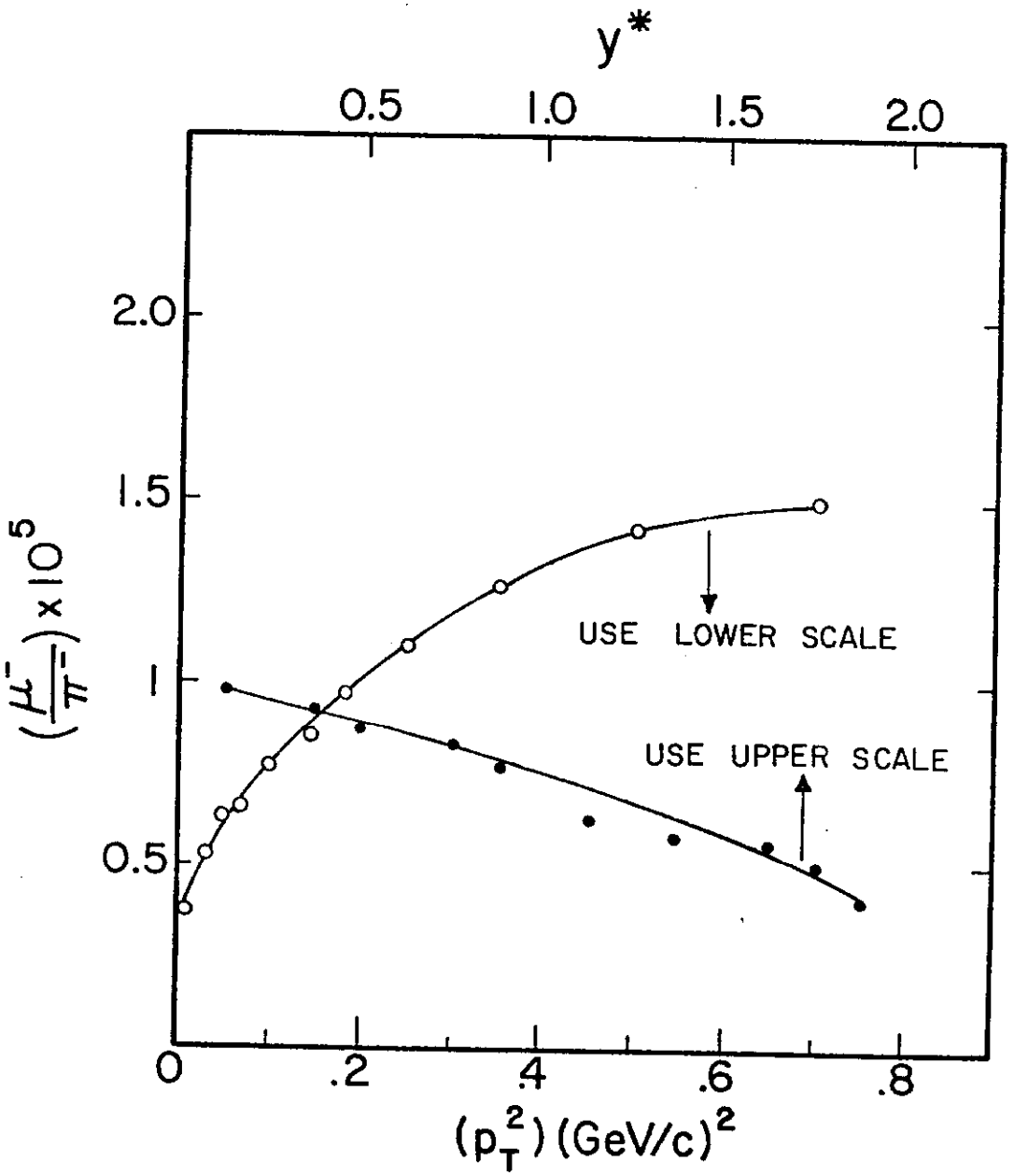
y*
0.5
1.0
1.5
2.0
2.0
1.5
1
0.5
$\left(\frac{\mu^-}{\pi^-}\right) \times 10^5$
USE LOWER SCALE
USE UPPER SCALE
0
.2
.4
.6
.8
(p_T^2) $(GeV/c)^2$

Fig. 4